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Extraction and Determination of Selected Polycyclic Aromatic Hydrocarbons in Plant Tissues

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16. ABSTRACT

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Extraction and Determination of Selected Polycyclic Aromatic Hydrocarbons in Plant Tissues

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A procedure has been developed for analysis of plant material for polycyclic aromatic hydrocarbons (PAHs). Sonication is used to extract the PAHs from homogenized plant material into acetonitrile and then the PAHs are partitioned into pentane. The pentane extract is fractionated on a micro silicic acid column and is analyzed by capillary gas chromatography with flame ionization detection. Overall method recoveries for 16 PAHs spiked into hybrid grain sorghum ranged from 45 to 90%, with relative standard deviations ranging from 3 to 38% and averaging 17%. This method can be used to measure PAHs in hybrid grain sorghum, fescue grass, and similar plants at the 25 μg/kg level. The procedure was applied to a preliminary study of PAH uptake by sorghum and fescue irrigated with secondary treated municipal wastewater spiked with 5 PAHs. Accumulation of fluoranthene and pyrene by fescue and hybrid grain sorghum from the PAH-contaminated irrigation water was apparent.

Polycyclic aromatic hydrocarbons (PAHs) have been under investigation as chemical carcinogens since at least 1930. Kennaway (1) reported that skin tumors in mice could be induced by dibenz[*a*,*h*]anthracene. Later, Cook et al. (2) isolated benzo[*a*]pyrene (B[*a*]P), a known chemical carcinogen, from coal tar extract thus establishing a connection between PAHs, cancer, and combustion processes. Since these early investigations, the ubiquitous nature of PAHs in the environment has been suggested by Tilgner (3) and reviewed by Baum (4). PAHs occur primarily as products of the combustion of organic matter, and have been demonstrated to be present in air, water, soils, sediments, plants, and many foodstuffs. Sources of contamination are numerous and occurrence of PAHs is diverse (5).

With developments in analytical procedures in the 1960s and improved multiresidue analyses in the 1970s, a large data base has accumulated on the presence of PAHs in food products and plants. However, a significant gap remains in analytical methods suitable for routine measurement of the uptake and accumulation of PAHs in plants. Sensitivity can be a problem, and the majority of available procedures are tedious, lengthy, and expensive to perform and therefore are not amenable to routine analyses. For example, Winkler et al. (6) described a method for the determination of PAHs with 3 to 7 rings in wet and dried maize. Samples were extracted by using a Soxhlet apparatus, rotary evaporated, saponified, filtered over silica gel, evaporated a second time, and partitioned on Sephadex LH 20. Howard et al. (7) described a method of similar complexity for root vegetables, using saponification, multiple solvent partitioning, solvent replacement, and adsorption chromatography on Florisil.

Joe et al. (8) used cyclohexane for extraction of PAHs from barley malt in an ultrasonic bath. Extracts were purified by column chromatography with deactivated silica gel and alumina, and partitioned between dimethyl sulfoxide and cyclohexane. Field and spiked samples were analyzed by liquid chromatography using fluorescence and ultraviolet detection, and recoveries of 78–97% were reported.

The objective of this investigation was to develop a method suitable for routine analysis of PAHs in plant tissues, with sensitivity sufficient for screening potential PAH uptake by plants growing under conditions of low to moderate exposure to PAH contamination, such as might occur next to a roadway, upon irrigation with wastewater, or during overland flow treatment of wastewater. Four extraction procedures were compared for recovery efficiencies and convenience. Sample cleanup and instrumental analyses were identical for the 4 extraction methods investigated. A sonication extraction method was found to be reliable and the most convenient. After development using spiked samples, the sonication method was applied in a field study of plants irrigated with PAH-spiked domestic wastewater. The method was found appropriate to measure PAH concentrations in hybrid grain sorghum and fescue at the 25 μg/kg level. To extract plant masses in excess of 20 g, additional sample cleanup would be required to remove interfering compounds.

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Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Experimental

Reagents

(a) *Solvents.*—Acetonitrile and pentane (Fisher Scientific pesticide grade).

(b) *Silicic acid.*—Unisil activated silicic acid, 100–200 mesh (Clarkson Chemical Co., Inc.).

(c) *PAHs.*—(Aldrich Chemical Co.). Acenaphthylene, 95%; fluoranthene, 98%; pyrene, 99+%; B[*a*]P, 98%; B[*g*,*h*,*i*]perylene, mp 277–279°C.

(d) *PAH standards.*—National Bureau of Standards (NBS) SRM 1647, 16 PAHs in acetonitrile (NBS, Gaithersburg, MD).

(e) *Laboratory blank water.*—Water, twice distilled in glass.

Apparatus

(a) *Sample preparation.*—Hobart® food processor Model 8181D.

(b) *Sonication extraction.*—Brinkmann Polytron® with PT-20ST probe generator.

(c) *Soxhlet extraction.*—Preextracted cellulose thimbles in Soxhlet extractor.

(d) *Batch extraction.*—150 mL Corning centrifuge tubes with Teflon®-lined screw caps. Ebenbach slide shaker.

(e) *Continuous liquid/solid extraction.*—Fabricated after Waggot (9).

(f) *Sample concentration.*—Kuderna-Danish concentrator, 250 or 500 mL capacity, fitted with 3-ball Snyder column and 10 mL graduated receiver.

(g) *Sample cleanup columns.*—Fisher Pasteur pipets.

(h) *Gas chromatography.*—Hewlett-Packard Model 5880 capillary gas chromatograph equipped with flame ionization detector and 30 m × 0.21 mm id SE-54 capillary column with 0.25 μm film thickness. Operating conditions: splitless injection; He carrier at linear velocity 33 cm/s; N_2 makeup; 1.8 μL injection of sample; injector temperature, 250°C; detector temperature, 350°C; temperature program: 70°C for 2 min, then 20°/min to 125°C, then 4°/min to 290°C, hold for 15 min.

(i) *Centrifuge.*—Sorvall Superspeed RC2B automatic, refrigerated, with GSA head.

(j) *Gas chromatograph–mass spectrometer.*—Varian-MAT Model CH5DF operated in EI mode; 70 eV ionization voltage;

Table 1. Concentrations and masses of PAHs used in field study

PAH	Concn in spiked wastewater, μg/L	Total mass applied in spiked wastewater to each container, μg
Acenaphthylene	1000	320 000
Fluoranthene	200	64 000
Pyrene	100	32 000
Benzo[a]pyrene	1.0	320
Benzo[g,h,i]perylene	0.5	160

Table 2. Retention times for 16 PAHs in NBS SRM 1647 standard

PAH	Mol. wt	Relative retention time (referenced to pyrene)
1. Naphthalene	128.2	0.272
2. Acenaphthylene	152.2	0.457
3. Acenaphthene	154.2	0.485
4. Fluorene	166.2	0.566
5. Phenanthrene	178.2	0.733
6. Anthracene	178.2	0.741
7. Fluoranthene	202.3	0.959
8. Pyrene	202.3	1.000
9. Benzo[a]anthracene	228.3	1.238
10. Chrysene	228.3	1.246
11. Benzo[b]fluoranthene	252.3	1.439
12. Benzo[k]fluoranthene	252.3	1.443
13. Benzo[a]pyrene	252.0	1.494
14. Indeno[1,2,3-cd]pyrene	276.3	1.739
15. Dibenz[a,h]anthracene	278.4	1.749
16. Benzo[g,h,i]perylene	276.3	1.805

60 m × 0.25 mm id DB-5 capillary column with 0.25 μm film thickness. Operating conditions: splitless injection; He carrier at 35 cm/s; injector temperature, 250°C; temperature program: 70°C for 2 min, then 20°/min to 125°C, then 4°/min to 290°C, hold for 15 min.

Sample Collection for Spiking Studies

Immature hybrid grain sorghum was harvested from the Clemson University Agricultural Experiment Station, Simpson farm, during the early fall of 1982 and was stored at −10°C until recovery studies were initiated. All plants were removed from storage and the aerial parts of the plants were homogenized in a Hobart food processor before spiking and subsequent method evaluation.

Sample Spiking for Method Development

A weighed portion (2–10 g) of plant mulch was placed in a 150 mL glass centrifuge tube with 1 mL PAH mixed standard (NBS SRM 1647). Laboratory blank water (150 mL) and 1 mL 185mM mercuric chloride (as a bactericide) were added to the tube. The tube was capped and placed on a slide shaker in a dark room for 24 h. After shaking, the contents were centrifuged at 5500 *g* for 20 min. The aqueous phase was transferred to a separatory funnel and extracted 3 times with 30 mL portions of pentane. Extracts were combined and concentrated using a 500 mL Kuderna-Danish (K-D) apparatus to ca 3–4 mL, then by dry nitrogen to 0.5 mL. The solid phase was extracted by one of 4 techniques: sonication using a Polytron homogenizer, batch shaking of liquid and solid, continuous liquid/solid extraction using a Soxhlet apparatus, or modified continuous liquid/solid extraction (CLS) (9).

After the aqueous and solid phases were removed and analyzed, the centrifuge tube was extracted 3 times with 10 mL portions of pentane. Tubes were extracted by shaking the pentane aliquots for 2 h on a slide shaker. The extracts were combined in a 250 mL K-D flask and concentrated to 0.5 mL as noted above.

Plant Extraction Techniques

Sonication.—Acetonitrile (75 mL) was added to the centrifuge tube containing the plant mulch. The sonication probe generator was immersed in the suspension tube and the mixture was sonicated 2 min at maximum speed. Contents were then centrifuged at 5500 *g* for 20 min and the centrifugate was quantitatively transferred to a 500 mL separatory funnel. The solid was washed with 25 mL acetonitrile, centrifuged, and the centrifugate was combined with the first extract. Pentane (50 mL) was added to the separatory funnel containing the acetonitrile and shaken vigorously for 2 min. Saturated sodium chloride (10 mL) was then added to the separatory funnel, followed by 350 mL laboratory blank water, and the mixture was shaken for 30–40 s. The immiscible phases were separated, the pentane layer was dried by passing it through a sodium sulfate column, and was drained into a 500 mL K-D apparatus.

Liquid/solid batch extraction.—The plant mulch remaining in the 150 mL glass centrifuge tube was extracted by vigorously shaking with three 30 mL portions of acetonitrile for 2 min each, and was then centrifuged at 5500 *g* for 20 min. The centrifugate was quantitatively transferred to a 500 mL separatory funnel. Solutes extracted into acetonitrile were partitioned into pentane, dried over a sodium sulfate column, and transferred to a 500 mL K-D concentrator as for the sonication procedure.

Soxhlet and CLS extraction.—In the Soxhlet extraction, plant mulch in the 150 mL centrifuge tube was quantitatively transferred to a preextracted cellulose thimble and covered with preextracted glass wool. The thimble was filled to capacity with acetonitrile, 200 mL acetonitrile was added to the solvent flask, and the mixture was extracted at a turnover rate of once every 10 min for 24 h.

For CLS extraction, the plant mulch from the spiking procedure was quantitatively transferred to the sample flask to which the distilling head and reflux column were attached. Acetonitrile (100 mL) was added to the solvent flask, which was connected to the distillation head. Samples were extracted at a turnover rate of 1 mL/min for 24 h. At the end of either the Soxhlet or the CLS extraction period, PAH extracts were transferred to 1 L separatory funnels and were partitioned into pentane. The ratio of acetonitrile, pentane, and water was 1.0:0.5:3. The immiscible layers were separated, the pentane layer was dried by passing it through a sodium sulfate column, and was drained into a 500 mL K-D concentrator as for the sonication procedure.

Concentration and Cleanup

Pentane extracts from each extraction method studied were concentrated to a volume of 3–4 mL in a 65°C water bath, removed, and allowed to cool for 10 min. The K-D flask was rinsed with 3 mL dry pentane and the 10 mL concentrator tube was removed from the flask. All ground glass joints were rinsed with 2 mL pentane, which was also collected in the concentrator tube. Each extract was then concentrated to 0.5 mL with dry nitrogen at room temperature, quantitatively transferred to a prewashed micro cleanup column containing 1.5 g silicic acid, and eluted with 5 mL dry pentane to remove, primarily, aliphatic hydrocarbons from the extract. The second and third 5 mL fractions were each eluted with pentane–methylene chloride (DCM) (85 + 15). All fractions were again concentrated to 0.5 mL with dry nitrogen and were analyzed by gas chromatography with flame ionization detection (GC-FID). All PAHs appeared in the second 5 mL fraction collected. No PAHs were ever found in the first (pentane) fraction or in the third (pentane–DCM) fraction. The cleanup

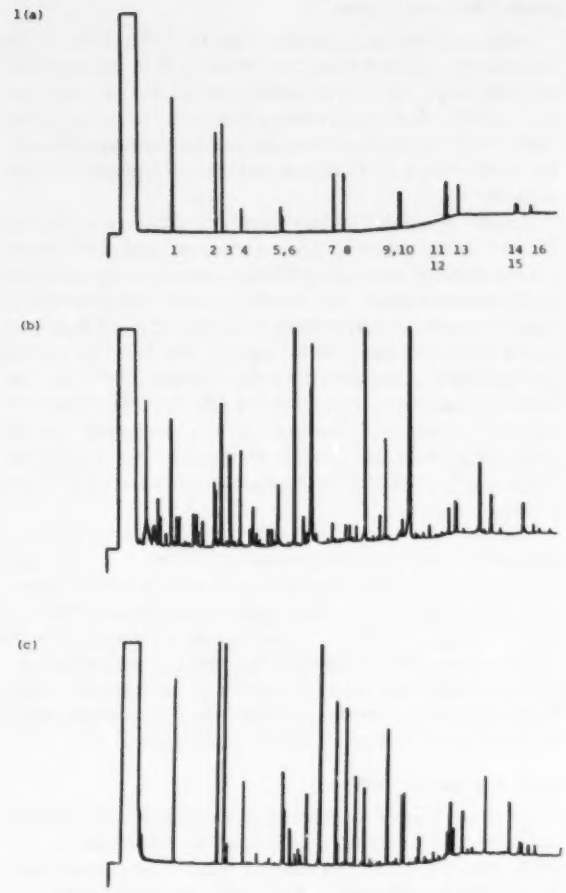

Figure 1. Chromatograms of (a) standard (numbered peaks appear in order as in Table 2); (b) plant extract eluted with pentane–DCM (75 + 25); (c) plant extract eluted with pentane–DCM (85 + 15).

procedure was sufficient for extracting up to 15 g air-dried plant material. When extracting more than 15 g plant material, additional silicic acid was required to remove interfering polar constituents. The method was scaled up on the basis of silicic acid pore volume to plant mass ratios.

Experimental Design for Field Study

This application of the method was initiated to demonstrate that the sonication technique would work with plant tissue that had incorporated PAHs during growth as well as with spiked samples. Hybrid grain sorghum and fescue were grown from seed in 20 L containers and were irrigated daily with PAH-spiked municipal sewage effluent for an 8 week period during the summer of 1983. Treated activated sludge effluent wastewater was obtained from the Coneross Waste Treatment Plant, Oconee County, South Carolina, and was stored with aeration at 4°C during the study period. The experimental design was a completely random design (CRD) with triplicate controls and triplicate PAH treatments. Polycyclic aromatic hydrocarbons used in this investigation were acenaphthylene, fluoranthene, pyrene, benzo[*a*]pyrene, and benzo[*g,h,i*]perylene. The concentration of PAHs in the spiked wastewater and the total mass of PAHs introduced to the growing plants during the spiked irrigation period are listed in Table 1.

The plants were irrigated using garden hand-pump pressurized spray cans. Containers were frequently moved to eliminate position in the growing area as a variable. The aerial part of each plant was harvested at the end of the growing season and was frozen until extracted. The seeds were planted in July, irrigation with spiked wastewater was begun in September, and the plants were harvested in November.

Results

Verification of Elution Order for PAHs

The elution order and corresponding relative retention times for the 16 PAHs present in the NBS SRM 1647 standard are listed in Table 2. Retention times for PAHs of different molecular weights were verified using gas chromatography on a DB-5 capillary column and selected ion monitoring mass spectrometry (GC-MS). The retention times for the remaining PAH molecular weight pairs (phenanthrene–anthracene, fluoranthene–pyrene, chrysene–B[*a*]A, and B[*b*]F–B[*k*]F) were determined by spiking the NBS standard with an EPA quality control sample containing one of the PAHs of the paired combinations and chromatographing with the same GC-MS technique, and noting the increase in area counts of the molecular ion peak for the spiked PAH. The chromatographic conditions used in this investigation are listed in *Experimental*.

Qualitative Evaluation of Cleanup Scheme

Plant extracts when concentrated typically contain high concentrations of polar organic compounds that co-elute and significantly interfere with many chromatographic analyses. To remove these materials, investigators have used a variety of cleanup schemes that often include one or more polar adsorbents such as silicic acid, alumina, or Florisil, and/or gel permeation chromatography (6, 10–13). Many of these cleanup schemes are complex and tedious to implement for routine analyses.

For this investigation, a single sorbent cleanup scheme coupled with solvent partitioning was sufficient to allow quantitation of all PAHs listed in Table 2.

PAHs extracted by acetonitrile were partitioned into pentane, dried on sodium sulfate, concentrated to 0.5 mL, and cleaned up on a micro silicic acid column as noted previously. Three 5 mL fractions were eluted with pentane and pentane–DCM solvent mixtures. Initially, a 75:25 ratio of pentane to DCM was used to elute the second and third 5 mL fractions.

Table 3. Recovery efficiencies of PAHs for concentration and cleanup steps

PAH		Mass spiked, µg	Mass recovered,[a] µg	Recovered, %
1.	Naphthalene	22.5	24.2 ± 0.92	108 ± 4
2.	Acenaphthylene	19.1	25.3 ± 0.61	132 ± 3
3.	Acenaphthene	21.0	27.3 ± 0.64	130 ± 3
4.	Fluorene	4.92	6.8 ± 0.12	138 ± 2
5.	Phenanthrene	5.06	6.7 ± 0.12	133 ± 2
6.	Anthracene	3.29	4.05 ± 0.07	123 ± 2
7.	Fluoranthene	10.10	11.71 ± 0.27	116 ± 3
8.	Pyrene	9.84	10.99 ± 0.12	112 ± 1
9.	B[*a*]A	5.03	5.21 ± 0.12	103 ± 2
10.	Chrysene	4.68	4.8 ± 0.16	102 ± 3
11.	B[*b*]F	5.11	4.9 ± 0.17	96 ± 3
12.	B[*k*]F	5.02	4.8 ± 0.13	95 ± 3
13.	B[*a*]P	5.30	5.1 ± 0.13	96 ± 2
14.	I[1,2,3,-cd]P	4.06	3.6 ± 0.23	88 ± 6
15.	D[*a,h*]A	3.68	3.8 ± 0.53	102 ± 14
16.	B[*g,h,i*]perylene	4.01	3.3 ± 0.07	83 ± 2

[a]Average of 4 replicates ± standard deviation.

Table 4. Overall method recovery efficiencies (PAH plant concentration 600–4500 μg/kg)

PAH	Mass in spike, μg	Recovered, %[a] Sonication	Shake	Soxhlet	CLS
1. Naphthalene	22.5	47 ± 1	32 ± 5	23 ± 5	26 ± 12
2. Acenaphthylene	19.1	81 ± 8	54 ± 4	45 ± 8	43 ± 15
3. Acenaphthene	21.0	80 ± 8	55 ± 5	46 ± 9	43 ± 16
4. Fluorene	4.92	82 ± 8	58 ± 2	56 ± 8	52 ± 11
5. Phenanthrene	5.06	90 ± 9	70 ± 8	73 ± 9	65 ± 10
6. Anthracene	3.29	82 ± 8	65 ± 6	64 ± 9	58 ± 12
7. Fluoranthene	10.1	83 ± 12	68 ± 12	73 ± 10	63 ± 8
8. Pyrene	9.84	83 ± 13	69 ± 14	75 ± 11	63 ± 8
9. B[*a*]A	5.03	72 ± 6	64 ± 16	72 ± 11	58 ± 6
10. Chrysene	4.68	71 ± 9	62 ± 16	75 ± 12	59 ± 6
11. B[*b*]F	5.11	62 ± 16	59 ± 15	66 ± 7	55 ± 6
12. B[*k*]F	5.02	61 ± 15	58 ± 14	64 ± 7	53 ± 5
13. B[*a*]P	5.30	57 ± 6	54 ± 15	59 ± 5	51 ± 8
14. I[1,2,3,-cd]P	4.06	49 ± 17	52 ± 17	30 ± 9	37 ± 2
15. D[*a,h*]A	3.68	45 ± 17	47 ± 17	20 ± 6	32 ± 3
16. B[*g,h,i*]perylene	4.01	61 ± 14	50 ± 16	26 ± 8	36 ± 1

[a]Average of 2 to 4 replicates ± standard deviation.

Table 5. PAH concentrations in hybrid grain sorghum irrigated with PAH-spiked domestic wastewater

PAH	Control, μg/g	Treated, μg/g
Acenaphthylene	ND[a]	ND
Fluoranthene	0.05	1.32
Pyrene	0.02	0.63
Benzo[*a*]pyrene	ND	ND
Benzo[*g,h,i*]perylene	ND	ND

[a]ND means not detected (less than approximately 0.02 μg/g).

This ratio was sufficient to clean up the extract from small quantities of plant material (0–5 g). However, when 15 g plant material was extracted, co-eluants interfered with the GC analysis. Optimization of the eluant solvent ratio was necessary to maintain the usefulness of the single adsorbent cleanup step.

Figure 1 (a–c) provides qualitative evidence for the utility of an 85:15 ratio of pentane to DCM in the eluant in lieu of the 75:25 mixture. Figure 1(a) is a chromatogram of the PAH standard with the peak identification corresponding to the numbers in Table 2. Figures 1(b) and 1(c) are chromatograms of the first 5 mL eluant fraction of plant extracts using a 75:25 and 85:15 pentane–DCM ratio, respectively. The greater complexity of the chromatogram for the pentane–DCM of 75:25 compared with the 85:15 solvent mix is evident. On the basis of these preliminary studies, a solvent mixture of 85:15 was used and was adequate to clean up plant extracts for the method development and field application phases of this study.

Analyte Recovery for Concentration and Cleanup Steps

To evaluate analyte loss attributable to the concentration and cleanup steps in these methods, four 10 g portions of hybrid grain sorghum that initially contained no measurable PAH concentrations were extracted with acetonitrile by using the sonication technique. Each extract was spiked with 1 mL NBS SRM 1647 standard, concentrated, and then cleaned up using the procedure outlined in *Experimental*. Results of this study are listed in Table 3. Recovery was quantitative for most PAHs, with the exception of indeno[1,2,3-cd]pyrene and benzo[*g,h,i*]perylene, which showed losses of 12 and 17%, respectively. Recoveries greater than 100% for the PAHs acenaphthylene through pyrene in Table 3 were consistently obtained, but were not found to be attributable to calibration procedures or blanks and remain unexplained.

Method Recovery Studies

Initial calibration studies for the 16 PAHs used in this investigation indicated detector linearity over the analytical working range, so a single point calibration curve was used to quantitate method recovery efficiencies. Standards (NBS SRM 1647) were injected into the gas chromatograph to monitor drift every 4 to 5 samples and were reproducible within ±5–7%.

Results of overall method recovery studies are listed in Table 4. These data were corrected for residual naphthalene, acenaphthylene, and acenaphthene concentrations remaining in the aqueous phase after incubation with the plant mulch. Aqueous phase concentrations of the remaining PAHs were below detectable limits (0.5–5 ng/μL). See *Experimental* for spiking details. Concentrations of PAHs spiked into the plant tissue homogenates were between 600 and 4500 μg/kg. For any given compound, the mass of that compound used for spiking was the same for each extraction technique investigated. Each technique was replicated at least once and up to 4 times.

Data in Table 4 suggest that the sonication procedure was generally more efficient in removing PAHs from the plant matrix than were the other extraction techniques. However, recovery efficiencies for naphthalene and the last 3 PAHs in Table 4 were low for all the extraction techniques. On the basis of these results, and the fact that the sonication technique was also the most convenient of the methods tested, the sonication extraction procedure was adopted and used in the field application phase of this investigation.

Field Application Studies

At the end of the 8 week growing period (see *Experimental*), the hybrid grain sorghum and fescue that were irrigated with PAH-spiked domestic wastewater were harvested and were stored frozen until extracted. All plants were analyzed using the sonication extraction, concentration, and cleanup schemes outlined.

Results are listed in Tables 5 and 6 for hybrid grain sorghum and fescue, respectively. Concentrations for each plant type are in μg PAH/g plant extracted. Direct error estimates for the data presented in Table 5 were not possible because replicates, for both control and treated samples, had to be combined to have enough plant material to extract. However, error estimates for the control and treatment were calculated and were used in significance analyses.

Fluoranthene and pyrene were found in the sorghum at concentrations significantly greater than the control. Four of the 5 PAHS (all but benzo[*a*]pyrene) were present in the fescue irrigated with spiked wastewater at concentrations greater than in the control. Concentration differences between samples and the controls were significant at the <0.01 level as determined by Student's *t*-test.

Table 1 gives the total mass of each PAH applied to the plants through the spiked irrigation water. No attempt was made to account for losses of PAHs due to sorption, biodegradation, photolysis, volatilization from soil surface, or transpiration, but only to determine if measureable quantities of PAHs could be found associated with growing plants irrigated with the spiked wastewater.

Conclusions

A relatively simple and rapid sonication probe technique for extraction of PAHs from selected forage crops has been described. Coupled with gas chromatography-flame ionization detection, the overall procedure has been shown to be applicable to determination of at least 16 PAHs with 2–6

Table 6. PAH concentrations in fescue irrigated with PAH-spiked domestic wastewater

PAH	Concn (av. ± std dev.), μg/g	
	Control	Treated
Acenaphthylene	ND[a]	0.58 ± 0.16
Fluoranthene	0.12 ± 0.03	50 ± 13
Pyrene	0.07 ± 0.03	24 ± 6
Benzo[a]pyrene	ND	ND
Benzo[g,h,i]perylene	ND	0.13 ± 0.03

[a]ND means not detected (less than approximately 0.02 μg/g).

condensed rings in plant tissue, yielding recoveries from samples spiked at the 25 μg/kg level of 45–90% with an average relative standard deviation of 17% (Table 4). The sonication extraction procedure was easier and gave superior extraction efficiencies compared with the shake, Soxhlet, and continuous liquid/solid extraction techniques tested. The utility of the sonication procedure was demonstrated in a preliminary plant uptake study involving irrigation of hybrid grain sorghum and fescue grass. Differential accumulation by the plants of selected PAHs, probably related to their different physical and chemical characteristics, was apparent. Further work is required to elucidate the mechanisms of uptake and accumulation of PAHs in plants.

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